TITLE OF THE INVENTION

OPTICAL AMPLIFIER WITH PUMP LIGHT SOURCE CONTROL FOR RAMAN AMPLIFICATION

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based on, and claims priority to, Japanese application number 2000-255291, filed August 25, 2000, in Japan, and which is incorporated herein by reference.

This application is related to U.S. application 09/531,015, filed March 20, 2000, and which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a Raman amplifier for amplifying a signal light in an optical communication system. More particularly, the present invention relates to a Raman amplifier for amplifying wavelength division multiplexed signal lights.

2. Description of the Related Art

Almost all optical amplifiers used in current optical communication systems are rare-earth doped optical fiber amplifiers. Particularly, erbium (Er) doped optical fiber amplifiers (EDFA) are commonly used.

Moreover, with wavelength division multiplexing (WDM) optical communication systems, a plurality of signal lights at different wavelengths are multiplexed together and then transmitted through a single optical fiber. Since an EDFA has a relatively wide gain band, WDM optical communication systems use EDFAs to amplify the multiplexed signal lights. Therefore, with WDM optical communication systems using EDFAs, the transmission capacity of an optical fiber can be greatly increased.

Such WDM optical communication systems using EDFAs are extremely cost effective, since they can be applied to previously laid optical fiber transmission line to greatly increase

the transmission capacity of the optical fiber transmission line. Moreover, an optical fiber transmission lines has virtually no limitation on bit rate since EDFAs can easily be upgraded in the future, as developments in optical amplifier technology occur.

Transmission loss of an optical fiber transmission line is small (about 0.3dB/km or less) in the wavelength band of 1450nm to 1650nm, but the practical amplifying wavelength band of an EDFA is in a range of 1530nm to 1610nm. Thus, an EDFA is only effective for amplifying signals in a portion of the wavelength band of 1450 nm to 1650 nm.

In a WDM optical communication system, a predetermined transmission characteristic may be obtained by suppressing fluctuation of optical power among each channel to 1dB or less in each optical repeating stage because the upper limit of optical power is caused by a non-linear effect and the lower limit by a receiving signal-to-noise ratio (SNR).

Here, a transmission loss wavelength characteristic of the transmission line and a dispersion compensation fiber or the like forming the WDM optical communication system must be reduced.

In a WDM optical communication system, the wavelength characteristic of transmission loss in a transmission line due to the induced Raman scattering provides the maximum influence on the wavelength characteristic of the signal light.

A key component of current WDM transmission systems is an EDFA that can amplify wavelength division multiplexed signal lights at the same time. For further improvement, such as increase of transmission capacity and realization of ultra-long distance transmission, it would be desirable to provide an optical amplifier which can amplify different wavelength bands than a conventional EDFA, while also providing the favorable characteristics of an EDFA.

In view of expanding the wavelength band of an optical amplifier to increase the transmission capacity of optical fibers, attention is being directed to a Raman amplifier.

A Raman amplifier can amplify the Stokes-shifted frequency that is shifted as much as the Raman shift of the amplifying medium from the frequency of a pump light. Therefore, a signal light can be amplified at a desired frequency with a pump light source producing a pump light of a desired wavelength.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a Raman amplifier for use in a WDM optical communication system.

More specifically, it is an object of the present invention to provide a control algorithm for a Raman amplifier using multiple pump light wavelengths or pump sources to attain a flat wavelength band over a wide band range.

It is also an object of the present invention to provide a control algorithm for a Raman amplifier that allows the amplifier to easily realize constant output power control, constant gain control and wavelength characteristic flattening control.

Additional objects and advantages of the invention will be set forth in part in the description which follows, and, in part, will be obvious from the description, or may be learned by practice of the invention.

The foregoing objects of the present invention are achieved by providing an optical amplifier including (a) an optical amplifying medium to Raman amplify a wavelength division multiplex (WDM) light including signal lights wavelength division multiplexed together; (b) pump light sources generating pump lights of different wavelengths; (c) a first optical multiplexer multiplexing the pump lights together; (d) a second optical multiplexer multiplexing the WDM light with the multiplexed pump lights; (e) a detector dividing the amplified WDM light into wavelength bands and detecting a power in each wavelength band; and (f) a pump light controller controlling power of each pump light based on a wavelength characteristic of gain generated in the optical amplifying medium for each wavelength bands, in accordance with the powers detected by the detector.

Objects of the present invention are also achieved by providing an optical amplifier including (a) an optical amplifying medium to Raman amplify a wavelength division multiplex (WDM) light including signal lights wavelength division multiplexed together; (b) pump light sources generating pump lights of different wavelengths; (c) a first optical multiplexer multiplexing the pump lights together; (d) a second optical multiplexer multiplexing the WDM light with the multiplexed pump lights; (e) an input detector detecting power of the WDM light before being amplified by the optical amplifying medium; (f) an output detector detecting power

of the amplified WDM light; and (g) a pump light controller controlling powers of the pump lights based on the power detected by the input detector and the power detected by the output detector.

Moreover, objects of the present invention are achieved by providing an optical amplifier including (a) an optical amplifying medium to Raman amplify a wavelength division multiplex (WDM) light including signal lights wavelength division multiplexed together; (b) pump light sources generating pump lights of different wavelengths; (c) a first optical multiplexer multiplexing the pump lights together; (d) a second optical multiplexer multiplexing the WDM light with the multiplexed pump lights; (e) a decoupler decoupling a portion of the amplified WDM light; (f) a detector dividing the decoupled portion into wavelength bands and detecting a power in each wavelength band; and (g) a pump light controller controlling power of each pump light based on a wavelength characteristic of gain generated in the optical amplifying medium for each wavelength bands, in accordance with the powers detected by the detector.

Further, objects of the present invention are achieved by providing an optical amplifier including (a) an optical amplifying medium to Raman amplify a wavelength division multiplex (WDM) light including signal lights wavelength division multiplexed together; (b) pump light sources generating pump lights of different wavelengths; (c) a first optical multiplexer multiplexing the pump lights together; (d) a second optical multiplexer multiplexing the WDM light with the multiplexed pump lights; (e) an input detector dividing the WDM light before being amplified in the optical amplifying medium into wavelength bands, and detecting the power in each wavelength band; (f) an output detector dividing the amplified WDM light into the same wavelength bands as the input detector, and detecting the power in each wavelength band; and (g) a pump light controller controlling powers of the pump lights based on the powers detected by the input detector and the powers detected by the output detector

In addition, objects of the present invention are achieved by providing an optical amplifier for amplifying a wavelength division multiplexed (WDM) light including signal lights wavelength division multiplexed together, the amplifier including (a) an optical amplifying medium to Raman amplify the WDM light in accordance with multiplexed pump lights of

different wavelengths traveling through the optical amplifying medium, the WDM light being amplified in a wavelength band divided into a plurality of individual wavelength bands; and (b) a controller controlling power of each pump light based on a wavelength characteristic of gain generated in the optical amplifying medium in the individual wavelength bands.

Objects of the present invention are also achieved by providing an optical amplifier for amplifying a wavelength division multiplexed (WDM) light including signal lights wavelength division multiplexed together, the amplifier including (a) an optical amplifying medium to Raman amplify the WDM light in accordance with multiplexed pump lights of different wavelengths traveling through the optical amplifying medium, the WDM light being amplified in a wavelength band divided into a plurality of individual wavelength bands; and (b) a controller controlling output powers of the pump lights in accordance with differences in power of the WDM light before being amplified by the optical amplifying medium and after being amplified by the optical amplifying medium in each individual wavelength band.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and advantages of the invention will become apparent and more readily appreciated from the following description of the preferred embodiments, taken in conjunction with the accompanying drawings of which:

FIG. 1 is a diagram illustrating the relationship between a pump light and gain wavelength during Raman amplification, according to an embodiment of the present invention.

FIG. 2 is a diagram illustrating enlargement of bandwidth of a Raman amplifier by multiplexing different wavelengths of different pump light sources, according to an embodiment of the present invention.

FIG. 3 is a diagram illustrating a Raman amplifier, according to an embodiment of the present invention.

FIGS. 4(A), 4(B) and 4(C) are diagrams illustrating wavelength characteristics of a single pump light source block of a Raman amplifier, according to an embodiment of the present invention.

FIGS. 5(A), 5(B) and 5(C) are diagrams illustrating wavelength characteristics of single pump light source block of a Raman amplifier, according to an embodiment of the present invention.

FIGS. 6(A) and 6(B) are diagrams illustrating control to obtain a constant wavelength characteristic, according to an embodiment of the present invention.

FIG. 7 is a flowchart illustrating the operation of a pump light controller in FIG. 3, according to an embodiment of the present invention.

FIG. 8 is a diagram illustrating a Raman amplifier, according to an embodiment of the present invention.

FIG. 9 is a diagram illustrating a wavelength characteristic when a desired number of monitor blocks are used in a Raman amplifier, according to an embodiment of the present invention.

FIG. 10 is a diagram illustrating a practical structure of a pump light source block and a wavelength multiplexing coupler in the Raman amplifiers of FIGS. 3 and 8, according to an embodiment of the present invention.

FIG. 11 is a diagram illustrating a portion of a Raman amplifier, according to an embodiment of the present invention.

FIG. 12 is a diagram illustrating a Raman amplifier, according to an embodiment of the present invention.

FIG. 13 is a flowchart illustrating the operation of a pump light controller in FIG. 12, according to an embodiment of the present invention.

FIG. 14 is a diagram illustrating a Raman amplifier, according to an embodiment of the present invention.

FIG. 15 is a diagram illustrating a Raman amplifier, according to an additional embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A Raman amplifier is used to compensate for output tilt of an EDFA.

In addition, attention is also paid to a Raman amplifier because the pump light is introduced into the transmission fiber. In this manner, the transmission fiber is used to compensate for deterioration of output using the transmission fiber as the Raman amplifying medium, to thereby provide transmission loss wavelength compensation of the transmission line due to the induced Raman scattering.

Raman amplifiers can mainly be considered for the following:

(1) Amplification outside of the wavelength band of EDFA.

(2) Improvement in output deviation compensation of an EDFA and improvement in optical SNR.

(3) Induced Raman scattering compensation of the transmission line.

In a WDM optical communication system, important characteristics for an optical amplifier are a wideband wavelength band, and a flat wavelength band.

It is now considered to use a plurality of pump lights of different wavelengths in view of realizing wide band transmission of a Raman amplifier. The Raman amplifier output is monitored or an output after insertion of an in-line amplifier after the Raman amplifier is monitored to control outputs of a plurality of pump LDs used to attain the band of the Raman amplifier to make small the output deviation.

When three or more pump light sources are used, the algorithms of the output power constant control or gain constant control and wavelength characteristic flattening control are extremely complicated.

Namely, with an increase in the number of pump wavelengths for realizing wide band and wavelength flattening or the number of pump light sources, more complicated control algorithms are required. Unfortunately, there are no conventionally known adequate algorithms.

Reference will now be made in detail to the present preferred embodiments of the present invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to like elements throughout.

FIG. 1 is a diagram illustrating the relationship between a pump light and gain wavelength during Raman amplification, according to an embodiment of the present invention.

Referring now to FIG. 1, pumps lights λ_{p1}, λ_{p2}, and λ_{p3} are pump lights for a Raman amplifier, and have associated Raman shifts of shift1, shift2 and shift 3, respectively. The center wavelength of gain and the gain bandwidth are shifted to a longer wavelength side as much as the shift of pump wavelength when the pump wavelength is shifted to the longer wavelength side.

Therefore, a Raman amplifier generates a gain at a respective wavelength that is shifted in amount of Raman shift of the amplifying medium from the pump light wavelength. The Raman shift amount and Raman bandwidth are intrinsically given to a substance (amplifying medium). Thus, Raman amplification is an optical amplification technique in which gain can be obtained at any desired wavelength if a pump light source having a desired wavelength can be provided.

FIG. 2 is a diagram illustrating enlargement of bandwidth of a Raman amplifier by multiplexing different wavelengths of different pump light sources, according to an embodiment of the present invention. Referring now to FIG. 2, a plurality of pump light sources provide pumps lights with wavelengths λ_{p1}, λ_{p2}, and λ_{p3}, which together form pump light 100 applied to an amplifying medium. Wavelengths λ_{p1}, λ_{p2}, and λ_{p3} are slightly different from each other. In this manner, gain 102 providing wideband optical amplification can be realized.

FIG. 3 is a diagram illustrating a Raman amplifier, according to an embodiment of the present invention. Referring now to FIG. 3, the Raman amplifier includes an input port 0, a Raman amplifying medium 1, a multiplexing coupler 2, a demultiplexing coupler 3, a multiplexing coupler 4, a wavelength branching coupler 5, pump light source blocks 6-1, 6-2 and 6-3, light receiving elements 7-1, 7-2 and 7-3 and a pump light controller 8.

A wavelength division multiplexed (WDM) light 104 including a plurality of signal lights multiplexed together is incident to back pumped Raman amplifying medium 1 from the input port 0.

Multiplexing coupler 4 is a wavelength multiplexing coupler multiplexing the pump lights of average wavelength of λ_{p1}, λ_{p2}, and λ_{p3} of different center wavelengths from pump light source blocks 6-1, 6-2 and 6-3, respectively.

Multiplexing coupler 2 is a wavelength multiplexing coupler multiplexing, in Raman amplifying medium 1, the multiplexed pump lights from multiplexing coupler 4 with signal lights traveling through Raman amplifying medium 1.

Demultiplexing coupler 3 is a light splitter demultiplexing the wavelength-multiplexed light amplified in Raman amplifying medium 1 with a ratio of, for example, 10:1.

Wavelength demultiplexing coupler 5 is a wavelength band demultiplexing coupler demultiplexing the Raman gain wavelength band generated with the pump light from pump light source blocks 6-1, 6-2 and 6-3 into monitor blocks 1, 2 and 3 (not illustrated in FIG. 3). Each monitor block 1, 2 and 3 has a corresponding wavelength band. Light receiving elements 7-1, 7-2 and 7-3 receive the wavelength bands, respectively, corresponding to monitor blocks 1, 2 and 3, respectively, and perform optical/electric conversion.

Pump light controller 8 controls the output powers of average wavelengths λ_{p1}, λ_{p2}, and λ_{p3} of pump light source blocks 6-1, 6-2 and 6-3 in accordance with the output of the signal light receiving elements 7-1, 7-2 and 7-3.

Control performed by pump light controller 8 will be explained below.

The average pump wavelength of pump light source block 6-1 is defined as λ_{p1}, and the output power of the pump light source block 6-1 is defined as P_{p1}. The average pump wavelength of the pump light source block 6-2 is defined as λ_{p2}, and the output power of pump light source block 6-2 is defined as P_{p2}. The average pump wavelength of pump light source block 6-3 is defined as λ_{p3}, and the output power of pump light source block 6-3 is defined as P_{p3}.

The average output power of the average wavelength λ_{s1} of the wavelength band of the monitor block 1 received with the light receiving element 7-1 is defined as P_{s1}. The average output power of the average wavelength λ_{s2} of the wavelength band of the monitor block 2 received with the light receiving element 7-2 is defined as P_{s2}. The average output power of the average wavelength λ_{s3} of the wavelength band of the monitor block 3 received with the light receiving element 7-3 is defined as P_{s3}.

FIGS. 4(A), 4(B) and 4(C) are diagrams illustrating wavelength characteristics of a single pump light source block of a Raman amplifier, according to an embodiment of the present invention..

More specifically, FIG. 4(A) is a diagram illustrating a wavelength division multiplexed light output from the amplifier when only pump light source block 6-1 is operated in the average pump wavelength of λ_{p1} and average pump output power of P_{p1}. Referring now to FIG. 4(A), a fine solid line 110 indicates the output spectrum while a thick solid line 112 indicates the average output power of each wavelength band monitor block by driving only P_{p1}.

FIG. 4(B) is a diagram illustrating a wavelength division multiplex light output from the amplifier when only pump light source block 6-2 is operated in the average pump wavelength λ_{p2} and average pump output power of P_{p2}. A fine solid line 114 indicates the output spectrum while a thick solid line 116 indicates the average output power of each wavelength band monitor block by driving only P_{p2}.

FIG. 4(C) is a diagram illustrating a wavelength division multiplex light output from the amplifier when only pump light source block 6-3 is operated in the average pump wavelength λ_{p3} and average pump output power of P_{p3}. A fine solid line 118 indicates the output spectrum while a thick solid line 120 indicates the average output power of each wavelength band monitor block by driving only P_{p3} .

As can be seen from FIGS. 4(A), 4(B) and 4(C), pump light source block 6-1 provides a maximum contribution to the signal light output of monitor block 1. Pump light source block 6-2 provides a maximum contribution to the signal light output of monitor block 2. Pump light source block 6-3 provides a maximum contribution to the signal light output of monitor block 3.

Simultaneously, pump light source block 6-1 also makes some contribution to the signal light output of monitor block 2 and the signal light output of monitor block 3. Pump light source block 6-2 makes some contribution to the signal light output of monitor block 1 and the signal light output of monitor block 2. Pump light source block 6-3 makes some contribution to the signal light output of monitor block 1 and signal light output of monitor block 2.

Therefore, pump lights of a plurality of wavelengths can used to form a wideband optical amplifier. At least one of the pump lights can be controlled, and will influence the other wavelength band monitor blocks.

In order to obtain a predetermined amplified signal power, a gain coefficient is multiplied by the power of a pump light source. Therefore, when the average power variation of the pump light outputs of the pump light source blocks 6-1 to 6-3 is defined as ΔP_p, the variation of

average output power of the band in which the gain is generated with the pump lights from the light receiving elements 7-1 to 7-3 is defined as ΔP_s and the average gain coefficient is defined as A, the following Formula 1 can be determined.

Formula 1

$$\Delta P_s = A \cdot \Delta P_p$$

To eliminate output power wavelength characteristic deviation of each wavelength block, ΔP_p can be adjusted to make identical the power levels of the wavelength-multiplex signal lights of wavelength bands demultiplexed into three bands with the wavelength demultiplexing coupler 5. ΔP_p can be adjusted, for example, by varying an optical output power of the pump light source, by varying the pump wavelength to shift the center of gravity wavelength and also by varying the pump light wavelength width. Here, an example of adjustment for varying an optical output power will be explained.

As illustrated in FIGS. 4(A), 4(B) and 4(C), since the gain wavelength band generated by one pump light source block is wide and the gain is generated over each monitor block, when one pump light source block is varied, Formula 1 must be calculated, considering the influence on the wavelength of the other monitor blocks.

In other words, regarding the power of each monitor block, an output power of each pump light source block should be controlled based on the wavelength characteristic of the gain generated in the optical amplifying medium of each pump light source block.

Here, the average gain coefficient of the average output power variation ΔP_{p1} of the pump wavelength λ_{p1} of the pump light source block 6-1 affecting on the average output power variation ΔP_{s1} of the monitor block 1 is defined as A_{11}. The average gain coefficient of the average output power variation ΔP_{p1} of the pump wavelength λ_{p1} of the pump light source block 6-1 affecting on the average output power variation ΔP_{s2} of the monitor block 2 is defined as A_{21}. The average gain coefficient of the average output power variation ΔP_{p1} of the pump wavelength λ_{p1} of the pump light source block 6-1 affecting on the average output power variation ΔP_{s3} of the monitor block 3 is defined as A_{31}.

The average gain coefficient of the average output power variation ΔP_{p2} of the pump wavelength λ_{p2} of the pump light source block 6-2 affecting on the average output power variation ΔP_{s1} of the block 1 of the monitor block is defined as A_{12}. The average gain coefficient

of the average output power variation ΔP_{p2} of the pump wavelength λ_{p2} of the pump light source block 6-2 affecting on the average output power variation ΔP_{s2} of the monitor block 2 is defined as A_{22}. The average gain coefficient of the average output power variation ΔP_{p2} of the pump wavelength λ_{p2} of the pump light source block 6-2 affecting on the average output power variation ΔP_{s3} of the monitor block 3 is defined as A_{32}.

The average gain coefficient of the average output power variation ΔP_{p3} of the pump wavelength λ_{p3} of the pump light source block 6-3 affecting on the average output power variation ΔP_{s1} of the monitor block 1 is defined as A_{13}. The average gain coefficient of the average output power variation ΔP_{p3} of the pump wavelength λ_{p3} of the pump light source block 6-3 affecting on the average output power variation ΔP_{s2} of the monitor block 2 is defined as A_{23}. The average gain coefficient of the average output power variation ΔP_{p3} of the pump wavelength λ_{p3} of the pump light source block 6-3 affecting on the average output power variation ΔP_{s3} of the monitor block 3 is defined as A_{33}.

FIGS. 5(A), 5(B) and 5(C) are diagrams illustrating wavelength characteristics of a single pump light source block of a Raman amplifier, according to an embodiment of the present invention.

More specifically, FIG. 5(A) illustrates the average output power difference of the monitor block 1, the monitor block 2 and the monitor block 3 for the pump light output power difference when only the pump light source block 6-1 is operated. Respective gradients correspond to A_{11}, A_{21}, A_{31}.

FIG. 5(B) illustrates the average output power difference of the monitor block 1, the monitor block 2 and the monitor block 3 for the pump light output power difference when only the pump light source block 6-2 is operated. Respective gradients correspond to A_{12}, A_{22}, A_{32}.

FIG. 5(C) illustrates the average output power difference of the monitor block 1, the monitor block 2 and the monitor block 3 for the pump light output power difference when only the pump light source block 6-3 is operated. Respective gradients correspond to A_{13}, A_{23}, A_{33}.

Here, the average gain coefficient matrix [A] including these elements can be obtained.

Formula 2

$$\begin{bmatrix}\Delta P_{S1}\\ \Delta P_{S2}\\ \Delta P_{S3}\end{bmatrix}=\begin{bmatrix}A_{11} & A_{12} & A_{13}\\ A_{21} & A_{22} & A_{23}\\ A_{31} & A_{32} & A_{33}\end{bmatrix}\begin{bmatrix}\Delta P_{P1}\\ \Delta P_{P2}\\ \Delta P_{P3}\end{bmatrix}$$

FIGS. 6(A) and 6(B) are diagrams illustrating control to obtain a constant wavelength characteristic, according to an embodiment of the present invention.

Referring now to FIG. 6(A), the average output of the monitor block 1, the monitor block 2 and the monitor block 3 when the wavelength characteristic of the signal light output has a large signal light spectrum is indicated with a thick solid line 122 and the average output P_f of the total wavelength band is indicated with a broken line 124.

Reduction of the wavelength characteristic deviation of the wavelength multiplex light output indicates that the average outputs P_{s1}, P_{s2} and P_{s3} of monitor blocks 1, 2 and 3, respectively, are matched, as illustrated in FIG. 6(B), with the target Raman-amplified wavelength multiplex light output P_f (average output of total wavelength band).

Formula 3

$$\begin{aligned}\Delta P_{s1} &= |P_f - P_{s1}|\\ \Delta P_{s2} &= |P_f - P_{s2}|\\ \Delta P_{s3} &= |P_f - P_{s3}|\end{aligned}$$

Formula 4

$$\Delta P_{s1} \approx \Delta P_{s2} \approx \Delta P_{s3}$$

Output difference (tilt) can be suppressed small in the total wavelength band where the Raman gain is generated in the Raman amplifying medium 1 by calculating the compensation amount of the pump light outputs P_{p1}, P_{p2} an P_{p3} of the pump light source blocks 6-1, 6-2 and 6-3, respectively, to satisfy the above formula.

Formula 5

$$\begin{bmatrix}\Delta P_{P1}\\ \Delta P_{P2}\\ \Delta P_{P3}\end{bmatrix}=\begin{bmatrix}A_{11} & A_{12} & A_{13}\\ A_{21} & A_{22} & A_{23}\\ A_{31} & A_{32} & A_{33}\end{bmatrix}^{-1}\begin{bmatrix}\Delta P_{S1}\\ \Delta P_{S2}\\ \Delta P_{S3}\end{bmatrix}$$

Namely, it is enough for the pump light controller 8 of FIG. 3 to control the pump light power output from each pump light source block 6-1, 6-2 and 6-3 by (a) monitoring the output power by dividing the wavelength-multiplex light where a plurality of signal lights are wavelength-multiplexed into the monitor blocks of the predetermined wavelength band, (b) executing the average value process obtained by dividing total output of the monitor block of each wavelength band with the number of channels, and (c) calculating, with the Formula 5, the average output power difference (tilt) of the pump light for weighting the influence on the wavelength of each monitor block of the pump wavelength of each pump light source block required to reduce the output power difference in the total wavelength band.

Moreover, the feedback control might typically be performed, for example, up to about ten (10) times until the predetermined wavelength characteristic deviation is obtained.

With these control processes, the average power of the Raman gain wavelength band generated with the pump light can be set to the constant power P_f.

FIG. 7 is a flowchart illustrating a process performed by pump light controller 8 in FIG. 3, according to an embodiment of the present invention. The processes in FIG. 7 can be performed, for example, such a processor, such as a CPU.

Referring now to FIG. 7, in operation 1, the control process is started.

From operation 1, the process moves to operation 2, where the average output powers P_{s1}, P_{s2} and P_{s3} in the monitor blocks 1, 2 and 3, respectively, are obtained from the outputs of the light receiving elements 7-1, 7-2 and 7-3, respectively.

From operation 2, the process moves to operation 3, where ΔP_{s1}, ΔP_{s2} and ΔP_{s3} are obtained by comparing the average wavelength output powers P_{s1}, P_{s2} and P_{s3} in the monitor block 1, 2 and 3, respectively, with the target wavelength multiplex output value P_f.

From operation 3, the process moves to operation 4, where it is determined whether the difference between ΔP_{s1} to ΔP_{s3} and P_f is within an allowable range. If the difference is within the allowable range, the process moves to operation 7 where the process stops. If the difference is not within the allowable range, the process moves to operation 5, where control amounts ΔP_{p1}, ΔP_{p2} and ΔP_{p3} of the power levels P_{p1}, P_{p2} and P_{p3} of the pump light source blocks 6-1, 6-2 and 6-3 are obtained, fromΔP_{s1}, ΔP_{s2}, ΔP_{s3}, using the inverse matrix of the average gain coefficients A_{11} to A_{33} which are affected on each monitor block by each pump light.

From operation 5, the process moves to operation 6, where the output powers P_{p1}, P_{p2} and P_{p3} of the pump light source blocks 6-1, 6-2, 6-3, respectively, are controlled by adding the control amounts ΔP_{p1}, ΔP_{p2}, ΔP_{p3} to the current P_{p1}, P_{p2}, P_{p3}, respectively.

From operation 6, the process moves to operation 7, where control process is completed.

In FIG. 3, as an example, a total pump light source block is provided as the three pump light source blocks 6-1, 6-2 and 6-3, and the total monitor block of the wavelength band that generates the gain through the pump light from the pump light source block is divided into three monitor blocks. However, the present invention is not limited to a total pump light source block provided "three" pump light source blocks, or a total monitor block as divided into "three" monitor blocks. Instead, the number of pump light source blocks of the total pump light source block and the number of monitor blocks of the total monitor block can be set to any practical number, which would typically be a matter of design choice.

For example, FIG. 8 is a diagram illustrating a Raman amplifier, according to an additional embodiment of the present invention. In FIG. 8, the number of pump light source blocks and monitor blocks can be set freely. Thus, in FIG. 8, n pump light source blocks (6-1 to 6-n) and m monitor blocks of the wavelength multiplex signal light are provided.

FIG. 9 is a diagram illustrating a wavelength characteristic when a desired number of monitor blocks are used in a Raman amplifier, according to an embodiment of the present invention. More specifically, FIG. 9 illustrates the wavelength band of the Raman amplification gain for the wavelength division multiplexed light decoupled by wavelength demultiplex coupler 5 in FIG. 8, with the wavelength band being divided into m monitor blocks.

Variation ΔP_p of the pump light power control is expressed as an n x 1 matrix. Difference ΔP_s between the average value of the wavelength multiplex signal light power in the monitor block and the target control value is expressed as the m x 1 matrix. A is expressed as the n x m matrix.

Formula 6

$$\begin{bmatrix} \Delta P_{S_1} \\ \Delta P_{S_2} \\ \bullet \\ \bullet \\ \Delta P_{S_n} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & \bullet & \bullet & A_{1m} \\ A_{21} & A_{22} & \bullet & \bullet & A_{2m} \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ A_{n1} & A_{n2} & \bullet & \bullet & A_{nm} \end{bmatrix} \begin{bmatrix} \Delta P_{P_1} \\ \Delta P_{P_2} \\ \bullet \\ \bullet \\ \Delta P_{P_M} \end{bmatrix}$$

ΔP_{pi}, in this case, is variation of the average output power of the pump light source, while ΔP_{sj} is variation of the average output power of the signal light monitor block.

Since variation is used, it is not required to convert the monitor output power to the main signal output power.

Here, it is understood that ΔP_{pi} resulting from ΔP_{sj} can be obtained by obtaining the inverse matrix $[A]^{-1}$ of $[A]$.

Formula 7

$$\begin{bmatrix} \Delta P_{P_1} \\ \Delta P_{P_2} \\ \bullet \\ \bullet \\ \Delta P_{P_m} \end{bmatrix} = A^{-1} \begin{bmatrix} \Delta P_{S_1} \\ \Delta P_{S_2} \\ \bullet \\ \bullet \\ \Delta P_{S_n} \end{bmatrix}$$

Therefore, reduction of deviation of the average output power among each block indicates flattening of the wavelength characteristic of the signal light output power.

In the embodiment of FIG. 3, the desired number of pump light source blocks and monitor blocks is not limited to any particular number and can be determined in accordance with design choice. However, it is preferable that the number of monitor blocks be less than the number of

signal light channels multiplexed to the wavelength multiplex light, and exceeding the number of pump light source blocks.

FIG. 10 is a diagram illustrating a practical structure of a pump light source block and a wavelength multiplexing coupler in the Raman amplifiers of, for example, FIGS. 3 and 8, according to an embodiment of the present invention. Referring now to FIG. 10, the embodiment includes WDM couplers 24 and 25, deflection composite couplers 61, 62 and 63, fiber grating filters 51, 52, 53, 54, 55 and 56, and semiconductor lasers 81, 82, 83, 84, 85 and 86.

The pump light source block 6-1 includes semiconductor lasers 81 and 82. The pump light source block 6-2 includes semiconductor lasers 83 and 84. The pump light source block 6-3 includes semiconductor lasers 85 and 86. Semiconductor lasers 81 and 82 have slightly different wavelengths. Semiconductor lasers 83 and 84 have slightly different wavelengths. Semiconductor lasers 85 and 86 have slightly different wavelengths. In the example of FIG. 10, the various pairs of semiconductor lasers have wavelengths which are about 4 nm apart, but the present invention is not limited to this specific wavelength difference.

The pump lights from the semiconductor lasers 81 and 82 are at, for example, wavelengths 1429.7nm and 1433.7nm, respectively, and are reflected at the fiber grating filters 51 and 52, respectively, to provide a resonance structure to output a pump light of the particular wavelength. PBS coupler 61 multiplexes these pump lights, to provide a pump light provided by pump light source block 6-1.

The pump lights from the semiconductor lasers 83 and 84 are at, for example, wavelengths 1454.0nm and 1458.0nm, respectively, and are reflected at the fiber grating filters 53 and 54, respectively, to provide a resonance structure to output a pump light of the particular wavelength. PBS coupler 62 multiplexes these pump lights, to provide a pump light provided by pump light source block 6-2.

The pump lights from the semiconductor lasers 85 and 86 at, for example, wavelengths 1484.5nm and 1488.5nm, respectively, and are reflected at the fiber grating filters 55 and 56, respectively, to provide a resonance structure to output a pump light of the particular wavelength. PBS coupler 63 multiplexes these pump lights, to provide a pump light provided by pump light source block 6-3.

The polarization coupling by PBS couplers 61, 62 and 63 is performed, for example, to eliminate dependence on change of the Raman amplification.

The multiplex coupler 4 includes the WDM couplers 24 and 25. The WDM coupler 25 operates, for example, by reflecting the wavelength light from the pump light source block 6-2 and transferring the wavelength from the pump light source block 6-3. The WDM coupler 24 operates, for example, by reflecting the wavelength light from the pump light source block 6-1 and transferring the wavelength from the pump light source block 6-3.

In FIG. 10, in each pump light source block 6-1, 6-2 and 6-3, the various semiconductor laser-fiber grating pairs output light which is slightly different in wavelength from each other. However, the present invention is not limited to this, and equal wavelength can be output. Moreover, the light of each pump light source block is not required to be formed with a plurality of semiconductor lasers. For example, a pump light of a pump light source block can be formed by a single light source which does not depend on polarization.

In FIG. 3, the target wavelength multiplex light output value is defined as P_f and the average powers of all wavelength bands are controlled to become equal to P_f. Therefore, it is possible to perform control to obtain constant output in all wavelength bands.

As a modified example of this constant output control, P_f is defined as P_{f1}, P_{f2}, P_{f3} for each wavelength band, or monitor block, of the total monitor block and these values are compared to conduct individual constant output control in the individual monitor blocks.

In this case, P_{f1}, P_{f2}, P_{f3} correspond to monitor blocks 1, 2 and 3, respectively, in place of P_f in operation 4 of the flowchart of FIG. 7.

The pump light controller 8 may also be controlled by subtracting the corresponding P_{s1}, P_{s2}, P_{s3} from the values P_{f1}, P_{f2}, P_{f3}.

FIG. 11 is a diagram illustrating a portion of a Raman amplifier, according to an embodiment of the present invention. Referring now to FIG. 11, weighting can be performed freely in monitor blocks 1, 2 and 3 to conduct constant output control individually in monitor blocks 1, 2 and 3, by providing, in place of changing P_f, variable or fixed attenuators 71, 72 and 73 in the preceding stage of the light receiving elements 7-1, 7-2 and 7-3 of FIG. 3.

Moreover, the embodiment in FIG. 3 can freely use, as the Raman amplifying medium, for example, dispersion compensation fiber (DCF) resulting in small effective sectional area and large

non-linearity, dispersion shifted fiber (DSF) and non-zero dispersion shifted fiber (NZDSF), as well as the ordinary 1.3 zero-micron fiber.

When fibers having large non-linearity are used, the length of the fiber that operates as the Raman amplifying medium to obtain the necessary gain can be shortened. Therefore, centralized amplification can be realized.

In the embodiment of FIG. 3, the wavelength demultiplex couplers 3 and 5, and light receiving elements 7-1, 7-2 and 7-3, are used to provide a monitor block. Instead, however, a spectrum analyzer can be used.

FIG. 12 is a diagram illustrating a Raman amplifier, according to an additional embodiment of the present invention. In FIG. 12, a branching coupler 9, a wavelength demultiplexing coupler 10 and light receiving elements 11-1, 11-2 and 11-3 are also used to provide a monitor block, in addition to elements of FIG. 3.

In FIG. 12, a plurality of wavelength-multiplexed signals are provided the input port 0 of the Raman amplifier. The branching coupler 9 is a light splitter provided at the input port 0 to branch the wavelength-multiplexed signals by, for example, a 10:1 ratio.

The wavelength demultiplexing coupler 10 is a wavelength band branching coupler for dividing the Raman gain wavelength band generated from the pump light transmitted from the pump light source blocks 6-1, 6-2 and 6-3 into the three wavelength bands (monitor blocks), in a similar manner as the wavelength demultiplexing coupler 5. Namely, wavelength demultiplexing coupler 10 is a wavelength demultiplexing filter for demultiplex the Raman gain wavelength band into monitor blocks 1, 2 and 3 of the wavelength band.

The light receiving elements 11-1, 11-2 and 11-3 convert the optical power of the monitor blocks 1, 2 and 3, respectively.

Regarding monitor blocks 1, 2 and 3 isolated by the wavelength demultipexing coupler 10, the average output power of the average wavelength λ_{s1} of the monitor block 1 is defined as P_{in_s1}, the average output power of the average wavelength λ_{s2} of the monitor block 2 is defined as P_{in_s2}, and the average output power of the average wavelength λ_{s3} of the monitor block 3 is defined as P_{in_s3}.

The main signal light is incident to the back pumped Raman amplifying medium 1.

The pump light source blocks 6-1, 6-2 and 6-3 may be constructed, for example, as illustrated in FIG. 10 or may be realized in various embodiments like that for the embodiment in FIG. 3.

The signal amplified with the amplifying medium 1 is branched with branching coupler 3 by, for example, a 10:1 ratio, and divided into the three wavelength band blocks like that of the wavelength demultiplexing coupler 10.

The wavelength band of the wavelength demultiplexing coupler 5 respectively corresponds to the average wavelengths λ_{s1}, λ_{s2}, λ_{s3} of the monitor block of the wavelength branching coupler 10. The wavelength multiplex output power is photo-electrically converted in the light receiving elements 7-1, 7-2 and 7-3.

As with FIG. 3, the average output power of the average wavelength λ_{s1} of the monitor block 1 of the wavelength demultipexing coupler 5 is defined as P_{s1}, the average output power of the average wavelength λ_{s2} of the monitor block 2 is defined as P_{s2}, and the average output power of the average wavelength λ_{s3} of the monitor block 3 is defined as P_{s3}.

The pump light controller 8 controls the gain to a predetermined value with the monitor input from the light receiving elements 7-1, 7-2, 7-3, 11-1, 11-2 and 11-3.

Practical operations of the pump light controller 8 in FIG. 12 are explained below.

The average gains G_1, G_2, G_3 of monitor blocks 1, 2 and 3, respectively, can be obtained by subtracting P_{in_s1}, P_{in_s2}, P_{in_s3} obtained with the light receiving elements 11-1, 11-2 and 11-3 through isolation with the wavelength demultiplexing coupler 10 in the input port side from P_{s1}, P_{s2}, P_{s3} obtained with the light receiving elements 7-1, 7-2 and 7-3, respectively

.

Formula 8

$$G_1 = P_{s1} - P_{in\_s1}$$
$$G_2 = P_{s2} - P_{in\_s2}$$
$$G_3 = P_{s3} - P_{in\_s3}$$

The pump light average output power of each monitor block and the wavelength light average gain of each monitor block may be coupled with the average gain coefficient of each monitor block and when the pump light average output power variation amount is ΔP_p, the

signal light average output power variation amount is ΔG, and the average gain coefficient is A.

Formula 9

$$\Delta G = A \cdot \Delta P_p$$

[A] used in the embodiment for FIG. 3 indicates gradient of the signal light average output power of the pump light average output power. Therefore, the following relationship can also be established for the gain A defined here.

Formula 10

$$\begin{bmatrix} \Delta G_1 \\ \Delta G_2 \\ \Delta G_3 \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \begin{bmatrix} \Delta P_{p1} \\ \Delta P_{p2} \\ \Delta P_{p3} \end{bmatrix}$$

Here, the target gain level is defined as average gain G_f of the total wavelength band, the average gain of each monitor block is defined as G_1, G_2, G_3, the difference of G_f and G_1 is defined as ΔG_1, the difference of G_f and G_2 as ΔG_2 and the difference of G_f and G_3 as ΔG_3.

Formula 11

$$\begin{aligned} \Delta G_1 &= |G_f - G_1| \\ \Delta G_2 &= |G_f - G_2| \\ \Delta G_3 &= |G_f - G_3| \end{aligned}$$

In order to make small the gain wavelength deviation (tilt) in the total wavelength band, the average gain among monitor blocks is set equally to match with the average gain G_f of the total wavelength band.

Here, all wavelengths can be controlled to the constant gain by setting G_f to the predetermined value for obtaining the constant gain.

Formula 12

$$\Delta G_1 \approx \Delta G_2 \approx \Delta G_3$$

Therefore, it is possible to calculate ΔP_{p1}, $\Delta P_{p2,}$ ΔP_{p3} from the Formula 13 using the Formula 11.

Formula 13

$$\begin{bmatrix} \Delta P_{p1} \\ \Delta P_{p2} \\ \Delta P_{p3} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix}^{-1} \begin{bmatrix} \Delta G_1 \\ \Delta G_2 \\ \Delta G_3 \end{bmatrix}$$

Namely, the pump light controller 8 obtains total output of the monitor block of the wavelength multiplex light, executes the process to obtain the average value by dividing total output of the monitor block with the number of channels and controls the pump light source blocks of the monitor block by calculating the necessary average output difference of pump light considering the influence of the gain by each pump light source block on the wavelength of each monitor block in view of making small the gain difference in the total wavelength band.

The feedback controls are repeated, for example, up to ten (10) times until the wavelength characteristic deviation (tilt) of the gain of each monitor block of the Raman optical amplifier is eliminated.

FIG. 13 is a flowchart illustrating the operation of the pump light controller 8 in FIG. 12, according to an embodiment of the present invention. Referring now to FIG. 13, in operation 1, the control is started.

From operation 1, the process moves to operation 2, where the gains G_1, G_2 and G_3 of the monitor block are obtained, respectively, by subtracting the powers P_{in_s1}, P_{in_s2}, P_{in_s3} of the monitor blocks of the wavelength demultiplexing coupler 5 provided in the input side from the powers P_{s1} , P_{s2} and P_{s3}, respectively, of the monitor blocks of the wavelength demultiplexing coupler 5 provided in the output side of the optical amplifying medium 1.

From operation 2, the process moves to operation 3, where the target gain G_f is compared with the gains G_1, G_2 and G_3 in the monitor blocks to obtain the differences.

From operation 3, the process moves to operation 4, where the difference between ΔG_1, ΔG_2 and G_f is determined. When difference is within an allowable range in operation 4, the process moves to operation 7, where the process stops. When difference is not within the allowable range in operation 4, the process moves to operation 5.

In operation 5, control amounts ΔP_{p1}, ΔP_{p2} and ΔP_{p3} of the power levels Pp1, Pp2 and Pp3, respectively, of the pump light source blocks λ_{p1}, λ_{p2} and λ_{p3}, respectively, are obtained from ΔG_1, ΔG_2 and ΔG_3 using the average gain coefficients A_{11} to A_{33} which affects on each monitor block with each pump light.

From operation 5, the process moves to operation 6, where the output powers P_{p1}, P_{p2} and P_{p3} of the pump light source blocks 6-1, 6-2 and 6-3, respectively, are controlled by adding the control amounts ΔP_{p1}, ΔP_{p2} and ΔP_{p3} to the current P_{p1}, P_{p2} and P_{p3}, respectively.

With the flow explained above, the pump light controller 8 controls the individual pump light source blocks. In the embodiment of FIG. 12, like the embodiment of FIG. 3, the number of pump light source blocks and monitor blocks may be set freely.

Namely, when the number of pump light source blocks is set to n, while the number of monitor blocks is set to m, the Formula 10, Formula 11, Formula 12 and Formula 13 may be updated as follows.

Formula 14

$$\begin{gathered} G_1 = P_{s1} - P_{in\_s1} \\ G_2 = P_{s2} - P_{in\_s2} \\ \vdots \\ G_m = P_{sm} - P_{in\_sm} \end{gathered}$$

Formula 15

$$\begin{pmatrix} \Delta G_1 \\ \Delta G_2 \\ \bullet \\ \bullet \\ \Delta G_m \end{pmatrix} = \begin{bmatrix} A_{11} & A_{12} & \bullet\ \bullet & A_{1n} \\ A_{21} & A_{22} & \bullet\ \bullet & A_{2n} \\ \bullet & \bullet & \bullet\ \bullet & \bullet \\ \bullet & \bullet & \bullet\ \bullet & \bullet \\ A_{m1} & A_{m2} & \bullet\ \bullet & A_{mn} \end{bmatrix} \begin{bmatrix} \Delta P_{P_1} \\ \Delta P_{P_2} \\ \bullet \\ \bullet \\ \Delta P_{P_n} \end{bmatrix}$$

Formula 16

$$\begin{aligned}\Delta G_1 &= |G_f - G_1| \\ \Delta G_2 &= |G_f - G_2| \\ &\vdots \\ \Delta G_m &= |G_f - G_m|\end{aligned}$$

Formula 17

$$\Delta G_1 \approx \Delta G_2 \approx \Delta G_m$$

Formula 18

$$\begin{bmatrix} \Delta P_{P_1} \\ \Delta P_{P_2} \\ \bullet \\ \bullet \\ \Delta P_{pn} \end{bmatrix} = A^{-1} \begin{bmatrix} \Delta G_1 \\ \Delta G_2 \\ \bullet \\ \bullet \\ \Delta G_m \end{bmatrix}$$

Thus, the pump light controller 8 could be designed in accordance with the above formula.

In the embodiment of FIG. 12, the number of pump light source blocks and monitor blocks can be set freely as in the case of the embodiment of FIG. 3, but it is preferable that the number of monitor blocks is set less than the number of signal light channels multiplexed in the wavelength multiplex signal, and exceeding the number of pump light source blocks.

Moreover, as with the embodiment of FIG. 3, the embodiment of FIG. 12 can freely use, as the Raman amplifying medium, a dispersion compensation fiber (DCF) resulting in small effective sectional area and large non-linearity, a dispersion shift fiber (DSF) and a non-zero dispersion shift fiber (NZDSF) as well as the ordinary 1.3 zero-micron fiber.

When an optical fiber operating as the Raman amplifying medium 1 has a large non-linearity, the fiber can be relatively short in length, while providing centralized amplification.

Moreover, when an optical fiber operating as the Raman amplifying medium 1 has a small effective cross-sectional area and intensive non-linearity, the Raman amplifying medium 1 can be structured in short length. However, when an ordinary 1.3 μm zero-discrete fiber is used, a length of about 40km or longer will probably be required depending on the pump power.

FIG. 14 is a diagram illustrating a Raman amplifier, according to a further embodiment of the present invention. More specifically, FIG. 14 illustrates an example where input of the wavelength multiplex light of the Raman amplifier of FIG. 12 is notified using the actual transmission line.

Referring now to FIG. 14, a monitor controller (OSC) 12 detects the power of each monitor block and transmits information of the result to the Raman amplifying medium 1 as the transmission line via a multiplexing coupler 13 in the wavelength of λ_{osc}. The signal of wavelength λ_{osc} is demultiplexed with the wavelength demultiplexing coupler 5 and detected with a monitor controller (OSC) 14 and is then supplied to the pump optical controller 8.

In FIG. 14, the wavelength λ_{osc} is demultiplexed with the wavelength demultiplexing coupler 5, but it is possible to additionally provide a branching coupler to the transmission line and to branch the monitor control signal and input this signal to the monitor controller 14.

In FIG. 13, the gain can be kept constant even when the Raman amplifying medium 1 is used in the transmission line through the embodiment explained above in the gain wavelength band of the amplifying medium 1 with the pump light from the pump light source block using the same value of G_f for all monitor blocks. The gain weighted for each wavelength band of each monitor block can be controlled to the constant value by setting the other gain G_f for each monitor block.

In addition, as with the embodiment in FIG. 3, with the embodiment in FIG. 12, the weighting process can be performed constantly to G_f for all wavelength blocks and it is also possible to conduct the weighting process by providing variable or fixed optical attenuators 71 to 73 in the preceding stage of the light receiving elements in unit of monitor block.

In the embodiment of FIG. 12, the monitor block is formed via the wavelength demultiplexing couplers 5 and 10, and light receiving elements 7-1, 7-2, 7-3, 11-1, 11-2 and 11-3, but these may be replaced with the spectrum analyzers.

The embodiments in FIGS. 3 and 13 can be combined with an optical amplifier using a rare-earth doped fiber (for example, an erbium-doped fiber).

For example, FIG. 15 is a diagram illustrating a Raman amplifier, according to an additional embodiment of the present invention. Referring now to FIG. 15, a first rare-earth doped fiber amplifier 13-1, a second rare-earth doped fiber amplifier 13-2, a wavelength band demultiplexing coupler 5-1, branching couplers 5-2, 5-3, 5-4 and 5-5, a first wavelength band monitor 5-6, a second wavelength band monitor 5-7, a first spectrum analyzer 5-8 and a second spectrum analyzer 5-9 are provided.

The wavelength band demultiplexing coupler 5-1 divides the wavelength multiplex light amplified with the Raman amplifying medium 1 to a first wavelength band (C-band: 1530nm to 1557nm) and a second wavelength band (L-band: 1570nm to 1610nm) and then outputs these divided wavelength bands.

The first rare-earth doped fiber amplifier 13-1 is an optical amplifier formed of an erbium-doped fiber (EDF) having the gain for the first wavelength band. The second rare-earth doped fiber amplifier 13-2 is an optical amplifier formed of an erbium-doped fiber (EDF) having the gain for the second wavelength band.

One light branched with the wavelength band demultiplexing coupler 5-1 is amplified by the first rare-earth doped fiber amplifier in the first wavelength band, and the other light branched with wavelength band demultiplexing coupler 5-1 is amplified by the second rare-earth doped fiber amplifier in the second wavelength band.

The branching couplers 5-2, 5-3 are branching couplers for branching the light of the first wavelength band in the ratio of, for example, 10:1. The branching couplers 5-4, 5-5 are branching couplers for branching the light of the second wavelength band in the ratio of, for example, 10:1.

The first wavelength band monitor 5-6 monitors the power of the first wavelength band light branched with the branching coupler 5-2. The second wavelength band monitor 5-7 monitors the power of the second wavelength band light branched with the branching coupler 5-4.

The pump light controller 8 calibrates the output powers of the first spectrum analyzer 5-8 and second spectrum analyzer 5-9 based on the outputs of the first and second wavelength monitors 5-6 and 5-7. Outputs of the spectrum analyzers 5-8 and 5-9 are divided to the wavelength band blocks of, for example, 1528.773 to 1552.122nm, 1552.524 to 1563.455nm, 1570.416 to

1581.601nm, and 1582.018 to 1607.035nm, to obtain the average output of each monitor block in view of controlling the pump lights 6-1, 6-2 and 6-3.

In the embodiment of FIG. 12, it is possible to use an output of the wavelength demultiplexing coupler 10 of FIG. 12 and FIG. 14 and use a method for detecting the signal before Raman amplification from the monitor controller 14 using the monitor control wavelength signal OSC.

According to the above embodiments of the present invention, a plurality of pump light sources are used to realize a wideband Raman amplifier with flattening of the wavelength characteristic of output and gain. The present invention enables control of wavelength characteristic deviation of output power and gain, control of constant output, and control of constant gain using a simplified control algorithm. In various embodiments of the present invention, the number of wavelength bands for monitoring an amplified light are higher than the number of individual blocks forming a pump light source block and lower than the number of signal channels.

In the various examples provided herein, specific wavelengths, frequencies and other values are provided for explanation purposes. However, the present invention is not limited to such specific wavelengths, frequencies or other values.

Although a few preferred embodiments of the present invention have been shown and described, it would be appreciated by those skilled in the art that changes may be made in these embodiments without departing from the principles and spirit of the invention, the scope of which is defined in the claims and their equivalents.